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LIGHTING GEOMETRY FOR THE APOLLO C' ALTERNATE 1 MISSION REVISION 1

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Lunar Mission Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER

HOUSTON,TEXAS

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PROJECT APOLLO

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By Edward M. Jiongo
Lunar Mission Analysis Branch

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MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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FIGURES

LIGHTING GEOMETRY FOR THE APOLLO C'

ALTERNATE 1 MISSION - REVISION 1

By Edward M. Jiongo

SUMMARY

Lighting conditions at the primary phases of the C' mission are of paramount interest to the flight crew as well as the recovery forces. These phases include earth orbit insertion, translunar injection, lunar orbit insertion, transearth injection, and touchdown.

This document shows lighting conditions (or reasonable approximations) at these critical mission points for all possible launch dates in December 1968 and January 1969.

INTRODUCTION

Figures 1 through 3 show lighting conditions at lift-off, lunar orbit insertion (LOI), transearth injection (TEI), and touchdown for all possible launch dates; figure 4 defines dip angle, and figures 5 through 9 show the lighting geometry at earth orbit insertion (EOI), translunar injection (TLI), LOI, TEI, and touchdown for the first and last possible launch dates in December 1968 and January 1969 and December 21, 1968.

The actual time a spacecraft spends in the shadow of the earth or moon depends primarily on the relative out-of-plane angles of the sun, earth, moon, and spacecraft; it is a three-dimensional effect. As a result, the spacecraft can cut the shadow cone of the earth or moon at an infinite number of angles, or miss it completely. Figures 5 through 9 in this document are two-dimensional. But since the earth, moon, sun, and spacecraft do not, in general, lie in the exact same plane these figures must necessarily be projections or approximations into a common plane. At the moon the lunar equatorial plane was chosen as the common plane (since the sun is always approximately a maximum of $\pm 1.5^{\circ}$ latitude), and the spacecraft lunar orbit always stays approximately within $\pm 8^{\circ}$ of this plane. Therefore, at the moon, the sun and spacecraft are almost in the lunar equatorial plane. At the earth, however, the geometry is quite different. Since the inclination of the spacecraft earth orbit for all possible launch azimuths is approximately 30° and during the months of December 1968 and January 1969 the sun is near its maximum southern declination of -23°, the out-of-plane angles are quite severe regardless of the plane chosen. In order to remain consistent with the lunar diagrams, the equatorial plane of the earth was chosen as the common plane.

Summarizing, figures 5 through 9 are meant only as overall visual representations of the lighting geometry existing at primary points in the mission. They are two-dimensional approximations of a three-dimensional effect. When a conflict seems to occur between figures 1 through 4 and 5 through 9, figures 1 through 4 take precedence.

DISCUSSION OF FIGURES

Figures 1(a) and 1(b) show the lighting conditions at lift-off for all possible launch azimuths and launch dates in December 1968 and January 1969, respectively. Figure 1 shows that all lift-offs for all possible azimuths take place between one-half hour before sunrise and one-half hour after sunset except on December 20, 26, 27, 1968, and January 23 and 24, 1969. On December 20 lift-offs with launch azimuths of 72° through 80° occur prior to one-half hour before sunrise; on December 26 lift-offs with launch azimuths of 88° through 108° occur after one-half hour after sunset; and on December 27 lift-offs with launch azimuths of 78° through 108° occur after one-half hour after sunset. On January 23 lift-offs with launch azimuths of 96° through 108° occur after one-half hour after sunset, and on January 24 lift-offs with launch azimuths of 83° through 108° occur after one-half hour after sunset.

Figures 2(a) and 2(b) show the lighting conditions at LOI and TEI for all possible launch dates in December 1968 and January 1969, respectively. The figures show the spacecraft orbital flight time from the spacecraft morning (or sunrise) terminator as a function of launch date. Flight time was computed on the basis of 3 deg/min since the period of the lunar parking orbit is approximately 120 minutes. Emphasis here, however, is on the word orbital. This means that if the spacecraft was in or near the nominal circular lunar parking orbit of 60-n. mi. altitude this time would be the spacecraft flight time from the terminator. At LOI and TEI ignition the spacecraft altitude is approximately 60 n. mi. Prior to LOI however, the spacecraft is not in a nominal or near-nominal lunar parking orbit. The spacecraft approach hyperbola may or may not intersect the lunar shadow cone. Figure 2 does not give or imply any lighting conditions prior to LOI ignition.

Figure 2 shows the spacecraft terminator as the reference point of orbital flight time. A negative time indicates the spacecraft is in darkness; a positive time indicates it is in sunlight. The lunar surface terminator is shown approximately 7 minutes, or 20°, from the projection of the spacecraft terminator on the lunar surface. (This difference between the surface and spacecraft terminators results from the fact that the spacecraft is not on the surface of the moon.) Therefore, the spacecraft terminator differs from the surface terminator by the dip angle as depicted in figure 4.

Figures 3(a) and 3(b) are similar to figures 1(a) and 1(b) except they depict lighting conditions at touchdown, not lift-off. The figures give launch date and the corresponding date of touchdown, and touchdown time is shown in G.m.t. and time zone W time. Time zone W time is the local clock reading at 165° W longitude. Touchdown occurs one-half hour or more prior to sunrise for launches on December 20 and 21, and January 18, 19, and 20. The latest local time of landing is near 11 a.m. considering both months.

It should be noted that the one-half hour before and one-half hour after sunset terminator lines in figure 1 are linear, while those in figure 3 are non-linear. The difference is due to the fact that lift-off always occurs at the same latitude while touchdown does not. During December the touchdown latitude ranges from approximately +10° to -23°; during January from +2° to -28°. Therefore, although the longitude of touchdown is constant, the latitude is not, and the time of sunrise or sunset varies non-linearly with latitude.

Figure 4 shows the geometry of what is known as the dip angle. AO is the radius vector from the central body to the spacecraft. AB is the line of sight from the spacecraft to the horizon of the reference body (earth or moon), and is tangent to the reference body at point B. OB is the line connecting the center of the reference body to this point of tangency and is equal to the radius. From plane geometry OB is perpendicular to AB and angle AOB = angle BAC. Therefore, the

dip angle = $\cos^{-1}(OB/OA)$.

If point B represents the sunlight terminator on the face of the reference body, the spacecraft terminator projected on the reference body is displaced from the surface terminator by the amount of the dip angle, in a direction away from the sun. For a 100-n. mi. altitude at the earth the dip angle is 13.6°; for a 60-n. mi. altitude at the moon the dip angle is 20.0°.

Figures 5 through 9 illustrate lighting conditions at the primary points in the mission for the first and last possible launch dates in December 1968 and January 1969. The lighting geometry for December 20, 21, and 27, and January 18 and 24 is shown. Since the operational trajectory will use a December 21, 1968 launch date (refs. 1 and 2) this day was also included. Each figure has two parts, (a) and (b); the (a) part is for a 72° launch azimuth, and the (b) part is for a 108° launch azimuth. By limiting the daily launch in this manner, the variations of the intermediate launch azimuths can be approximated. This same concept was applied to the monthly launch window by showing only the first and last days. Again, figures 5 through 9 are approximate projections into the equatorial planes of the earth or moon as previously stated.

Figure 5(a) is typical of figures 5 through 9. In figure 5(a) the lower left-hand diagram shows the sun terminator on the surface of the earth at time of EOI and TLI. While it is true that there is approximately 2 to 4 hours from EOI to TLI the shift in the sun terminator is too slight to be shown since the terminator moves inertially approximately 1° every 24 hours. The projection of the spacecraft terminator is shown as determined by the dip angle (13.6°) for a 100-n. mi. altitude. Also shown are the positions of the Greenwich meridian at EOI and TLI, the relative position of Aries, and the EOI and TLI burn arcs (approximately 25° and 23°, respectively). The height of the arc above the surface is not to scale since the ratio of the altitude of the spacecraft to the radius is extremely small. The earth-moon line shown is not the actual earth-moon line at time of TLI ignition, but rather the earth-moon line at the time of arrival of the spacecraft at pericynthion.

The upper left-hand diagram of figure 5(a) shows the sun terminator at LOI on the surface of the moon and the spacecraft terminator which differs from the surface terminator by the dip angle of 20° for a 60-n. mi. altitude. The upper right-hand diagram is similar, only it is for TEI, and the lower right-hand diagram shows earth touchdown. Again, the burn arcs are shown to approximate scale while the altitude above the earth and moon are not. The relative size of the earth and moon as well as the earth-moon distance have been disregarded for the sake of clarity. The earth-moon line connecting the centers of each body shows their relative position. Again, the second earth-moon line is not the actual earth-moon line at TEI ignition, but rather the line at time of earth touchdown.

Each diagram gives a typical or average time required for each burn, the ΔV involved, and the length of the burn arc.

From figures 5 through 9 it can be seen that the TLI burn always ignites very near the antipode of the moon. Since the sun elevation of the primary target site is always small this means that the far-eastern lunar target sites will generally correspond to a TLI burn in darkness.

For all days on which a western site is primary or on an eastern site up to approximately 13.6°, the TLI burn will be in sunlight. At TLI the spacecraft altitude increases from 100 to about 170 n. mi. which corresponds to an increase in the dip angle from 13.6° to 17.6°.

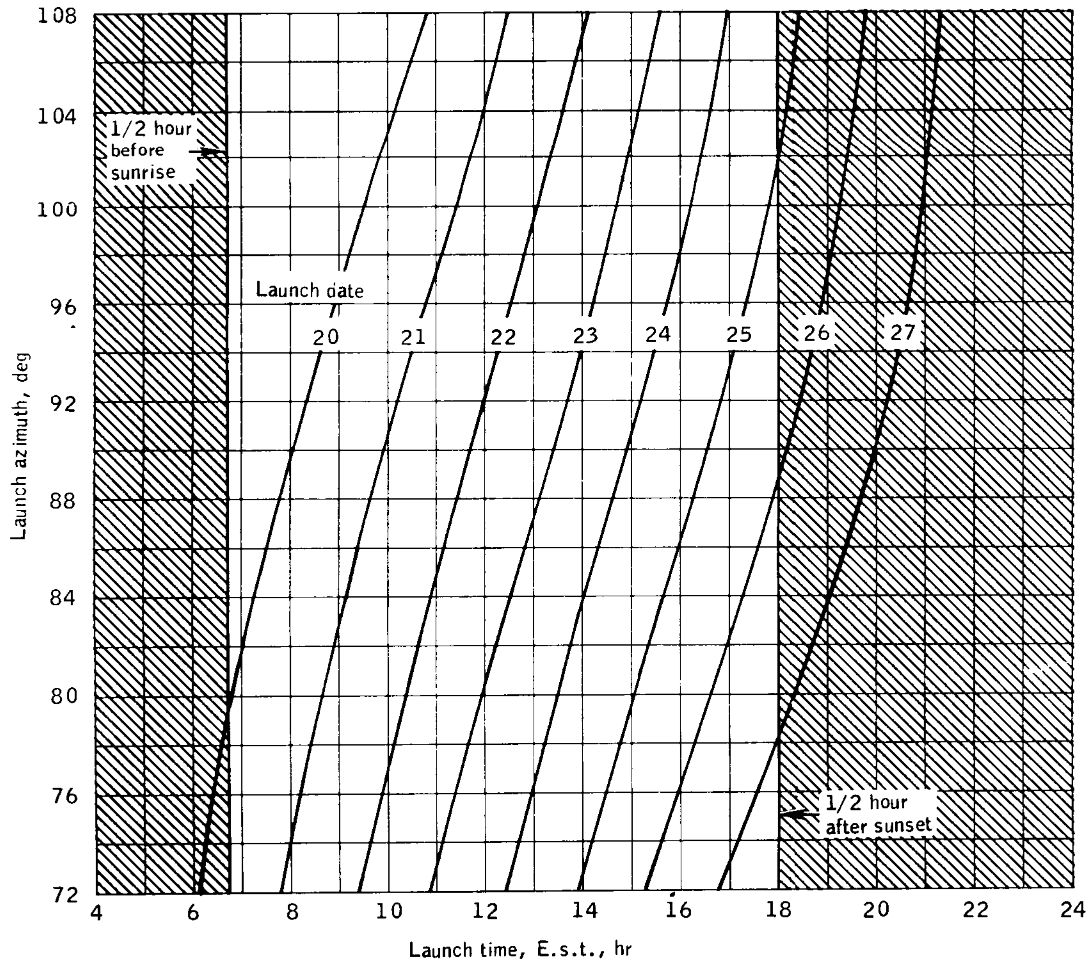
CONCLUDING REMARKS

The actual time spent by a spacecraft in the shadow of the earth or moon is difficult to define precisely for a mission such as C'. There are 15 possible different launch days with an infinite number of launch azimuths between the daily limit of 72° through 108°, each with its own unique geometry. This document presents reasonable approximations of the lighting conditions at the primary phases of the C' mission.

1967 N.ALMANAC' DEC. 21ST, 30° LAT. : 6:51 A.M. G.MT ⇒ 7:14 AM CAPE
SUNRISE

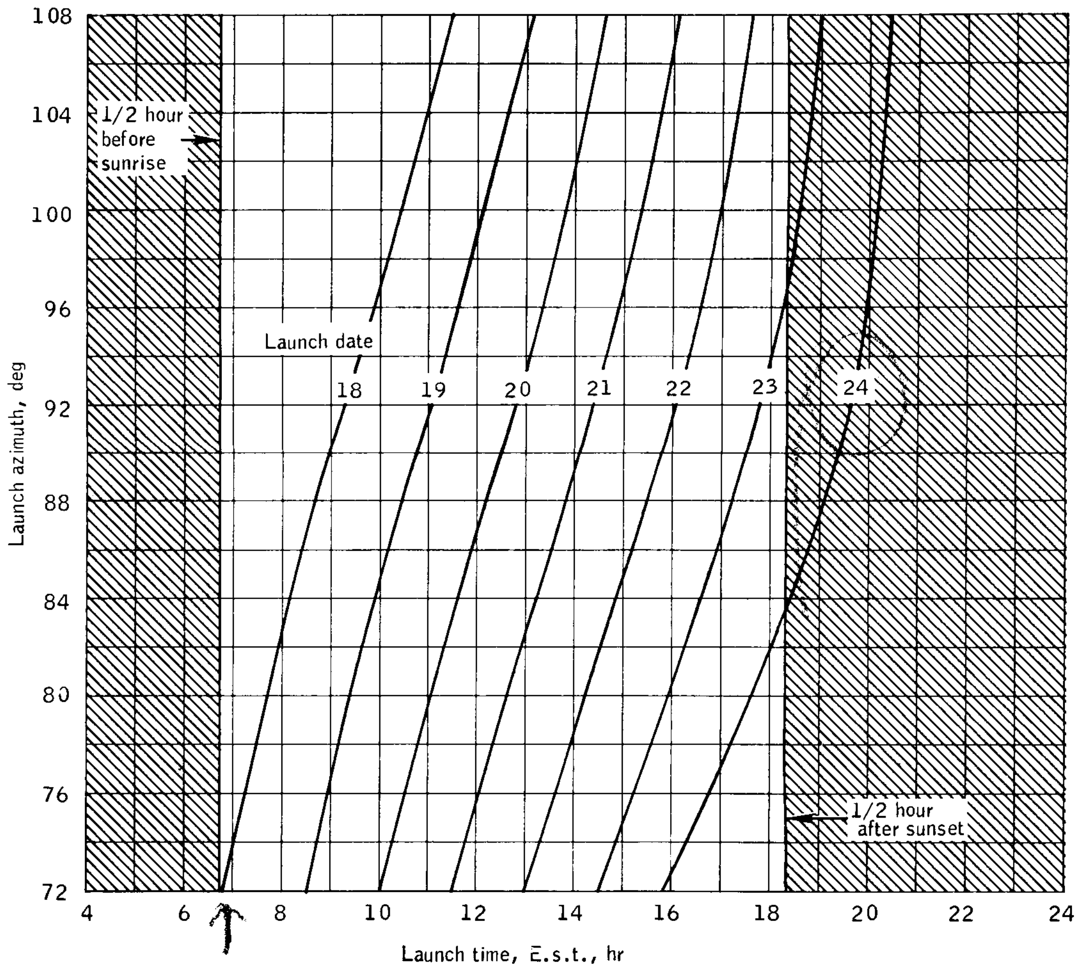
CAPE LATITUDE : 28°38'

17:?? P.M. ⇒ 17:27 P.M. CAPE
SUNSET



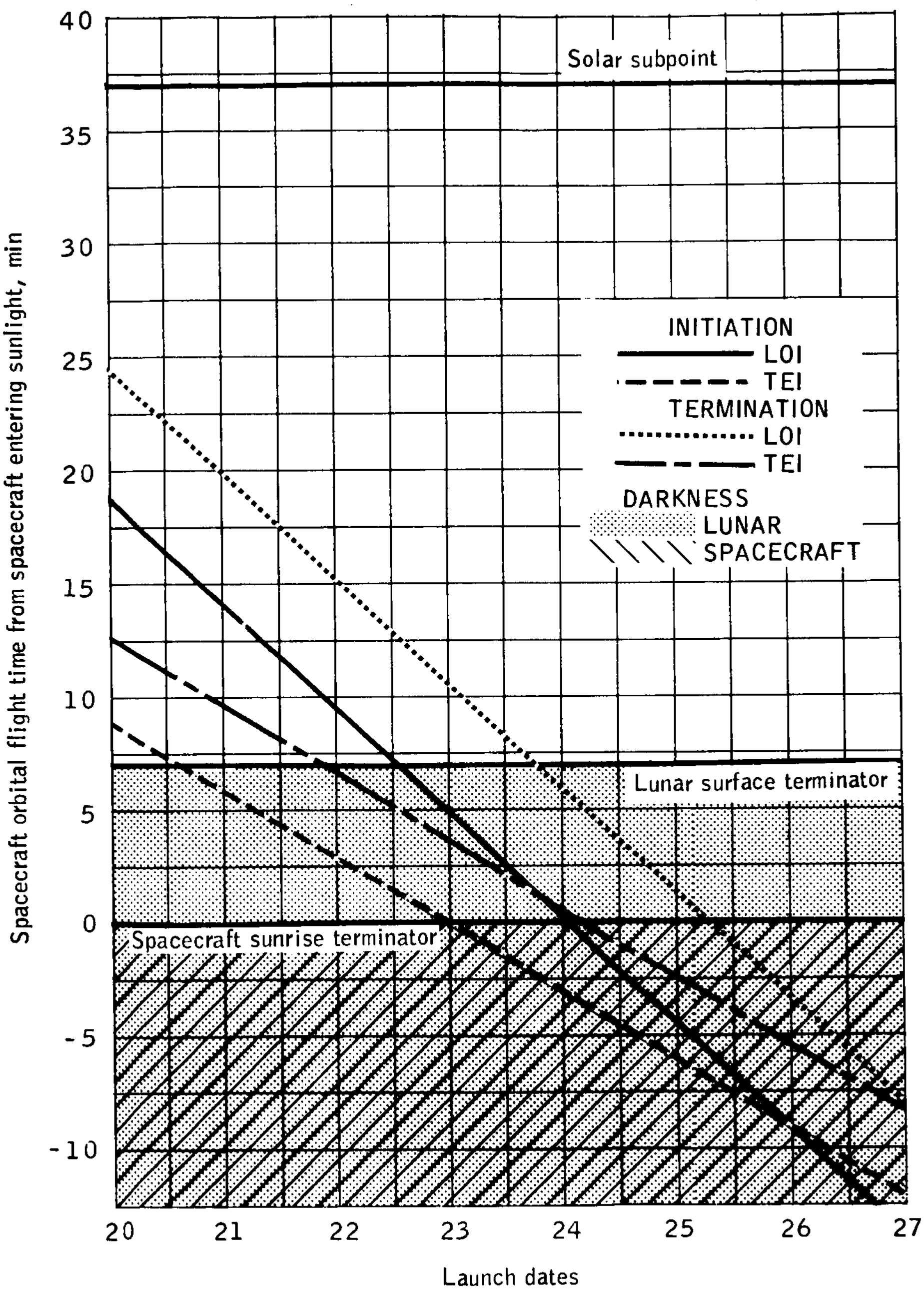
(a) December launch.

Figure 1.- Lighting conditions at lift-off for all possible launch dates and azimuths.



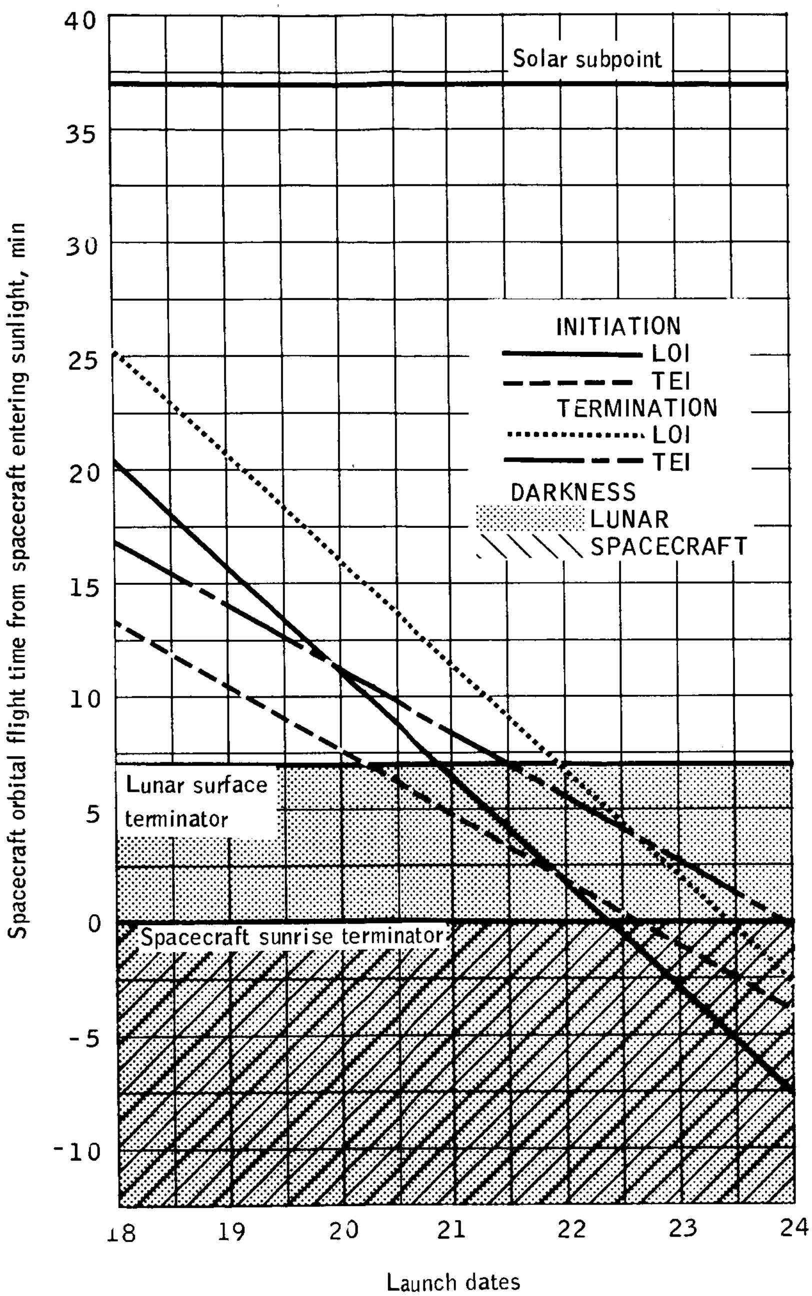
(b) January launch.

Figure 1.- Concluded.



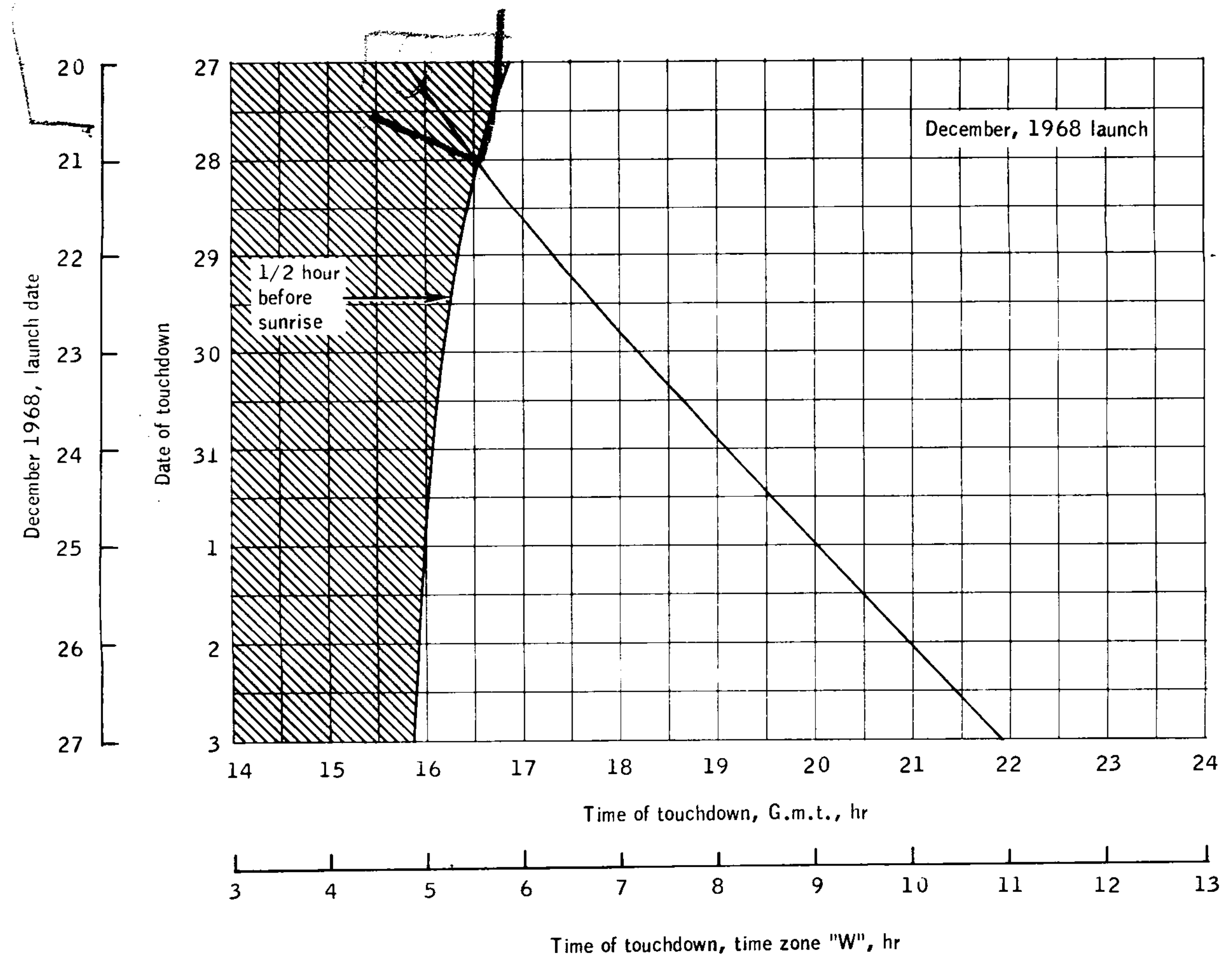
(a) December 1968

Figure 2.- Lunar lighting conditions.



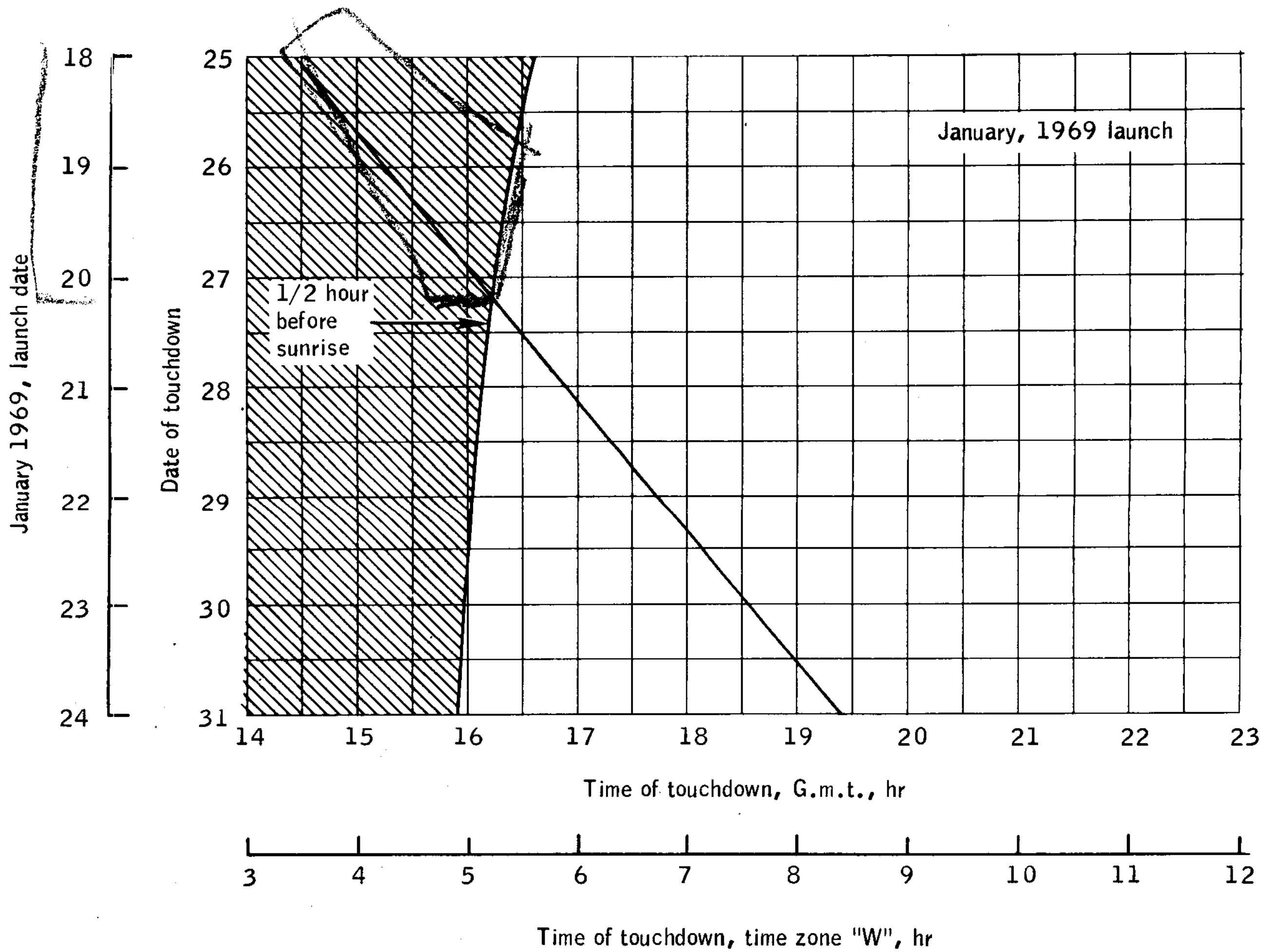
(b) January 1969

Figure 2.- Concluded.



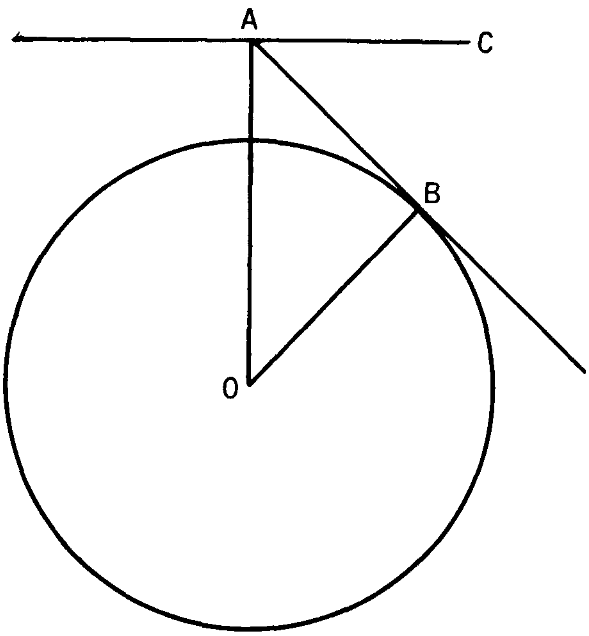
(a) December launch.

Figure 3.- Lighting conditions at touchdown for all possible launch dates.



(b) January launch.

Figure 3.- Concluded.

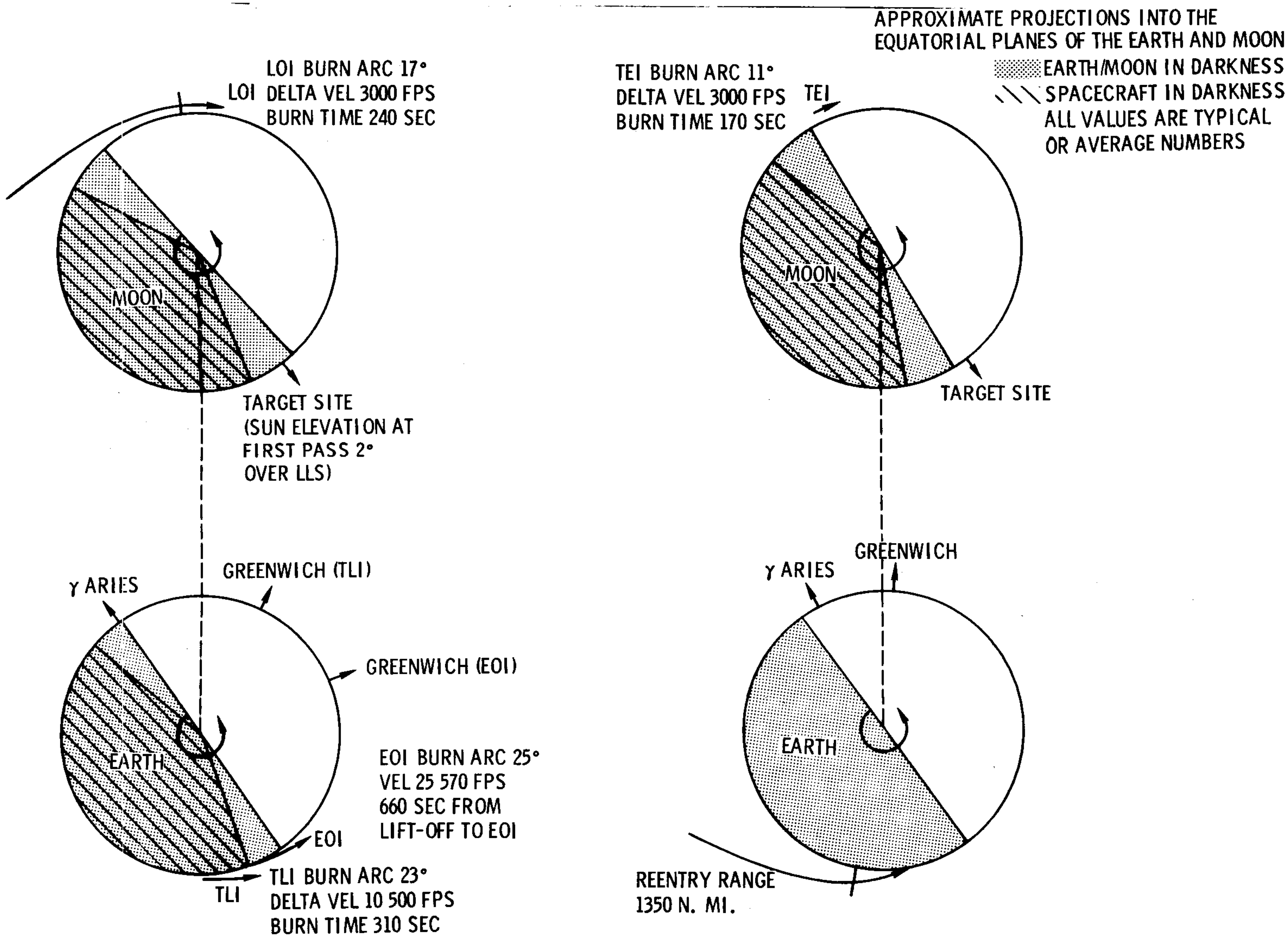


BO = RADIUS OF BODY (EARTH OR MOON)

AO = RADIUS OF BODY + SPACECRAFT ALTITUDE

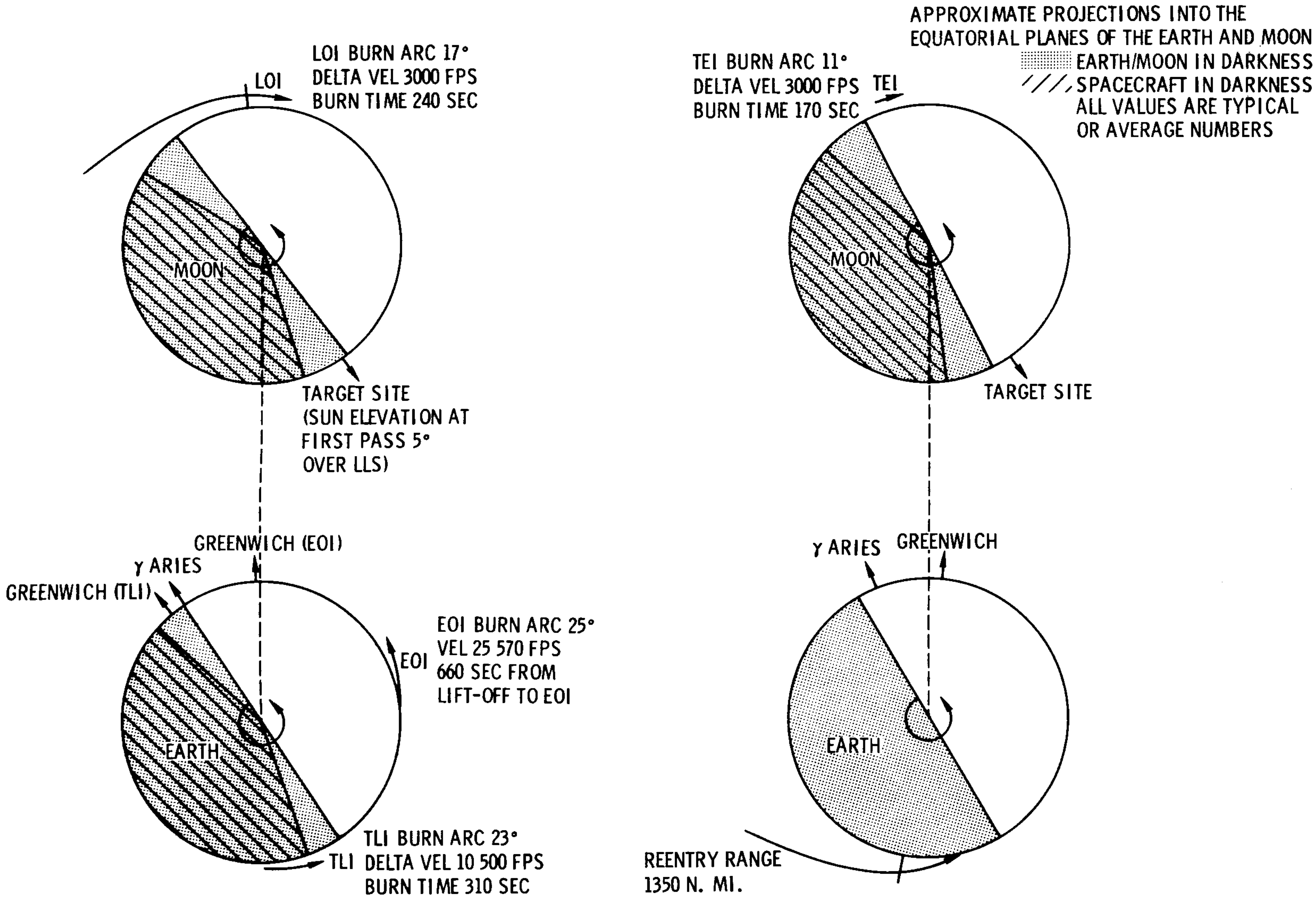
ANGLE AOB = ANGLE BAC = DIP ANGLE

Figure 4.- Dip angle.



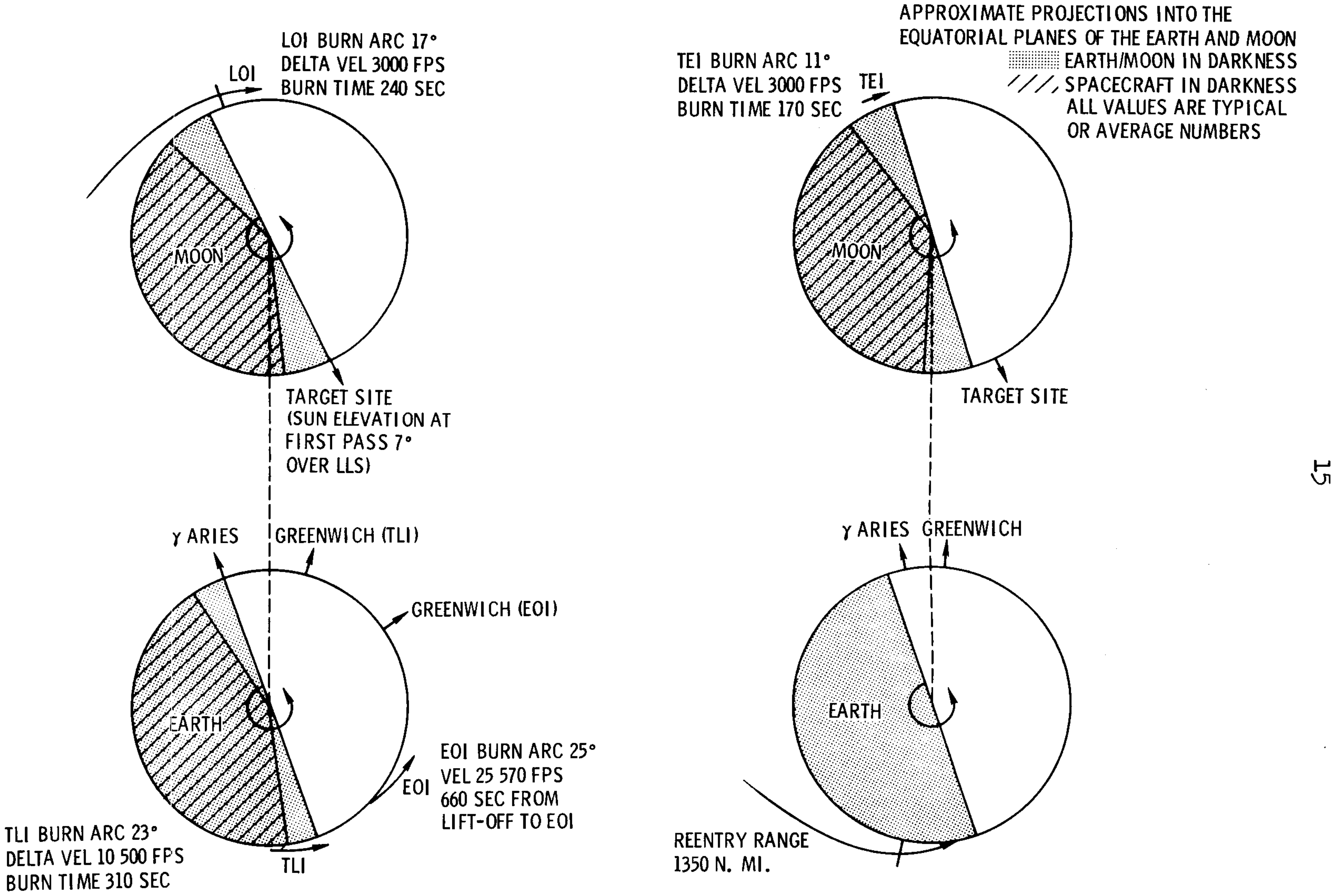
(a) 72 degree launch azimuth.

Figure 5.- Lighting geometry for December 20, 1968.



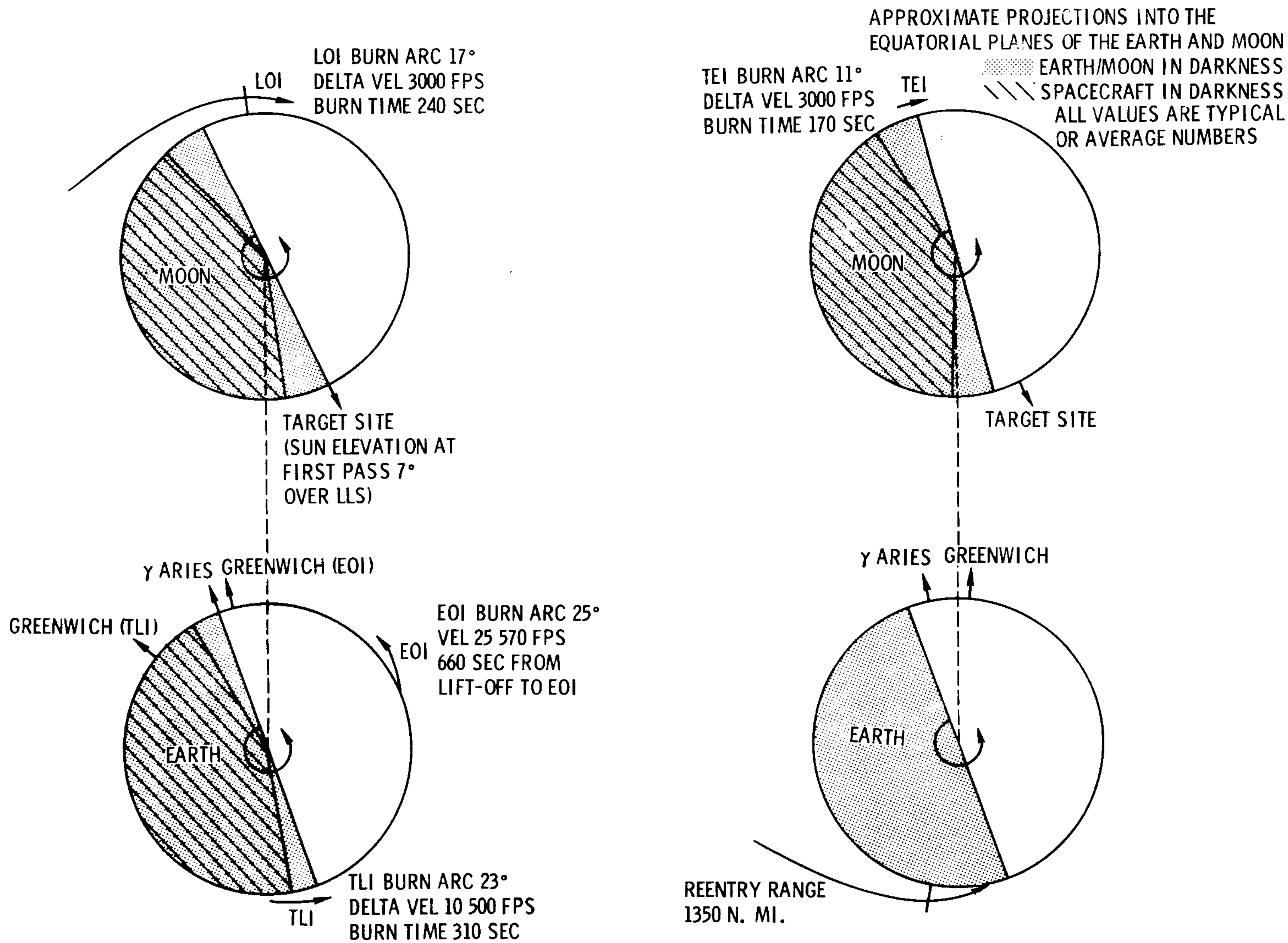
(b) 108 degree launch azimuth.

Figure 5. - Concluded.



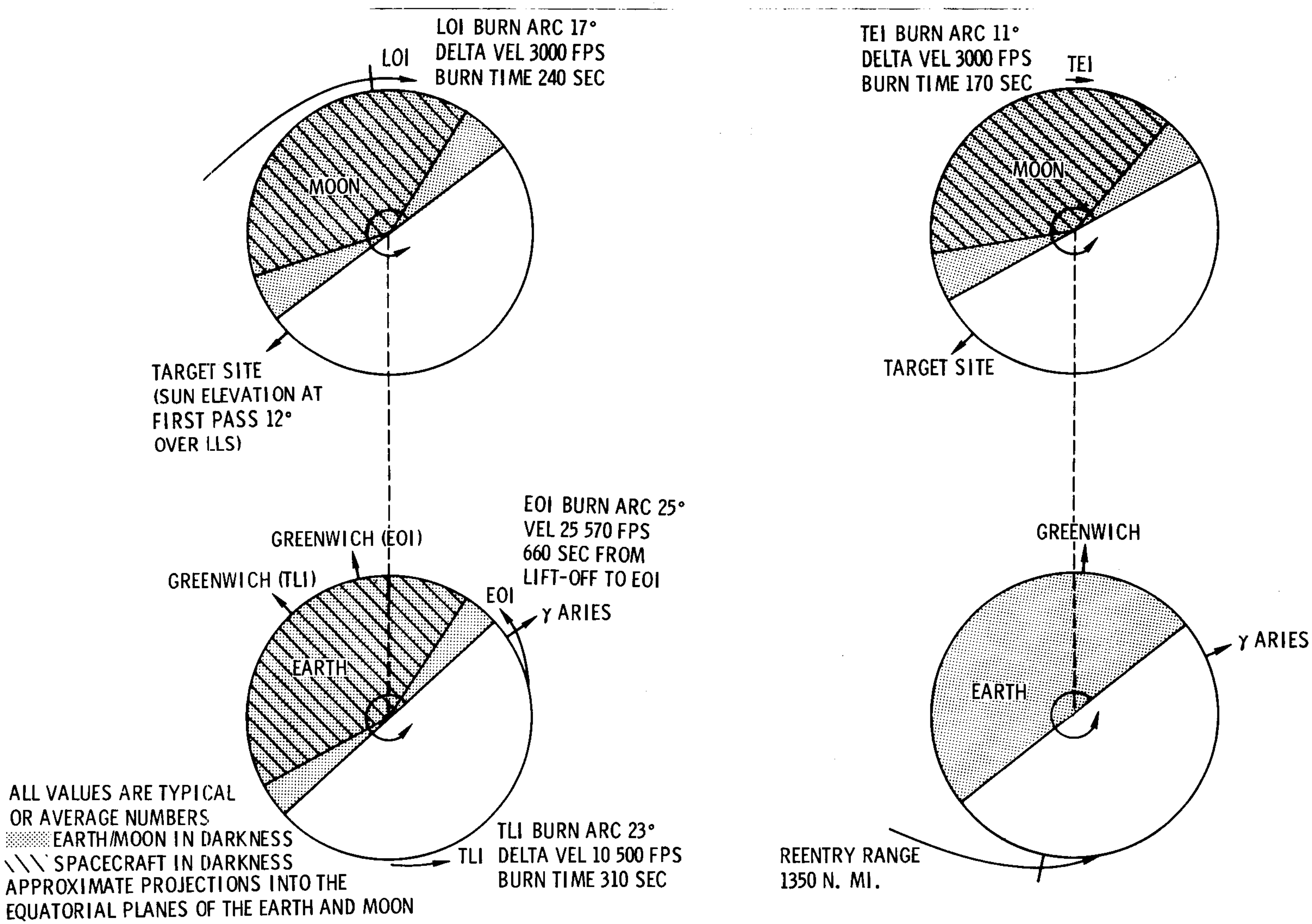
(a) 72 degree launch azimuth.

Figure 6.- Lighting geometry for December 21, 1968.



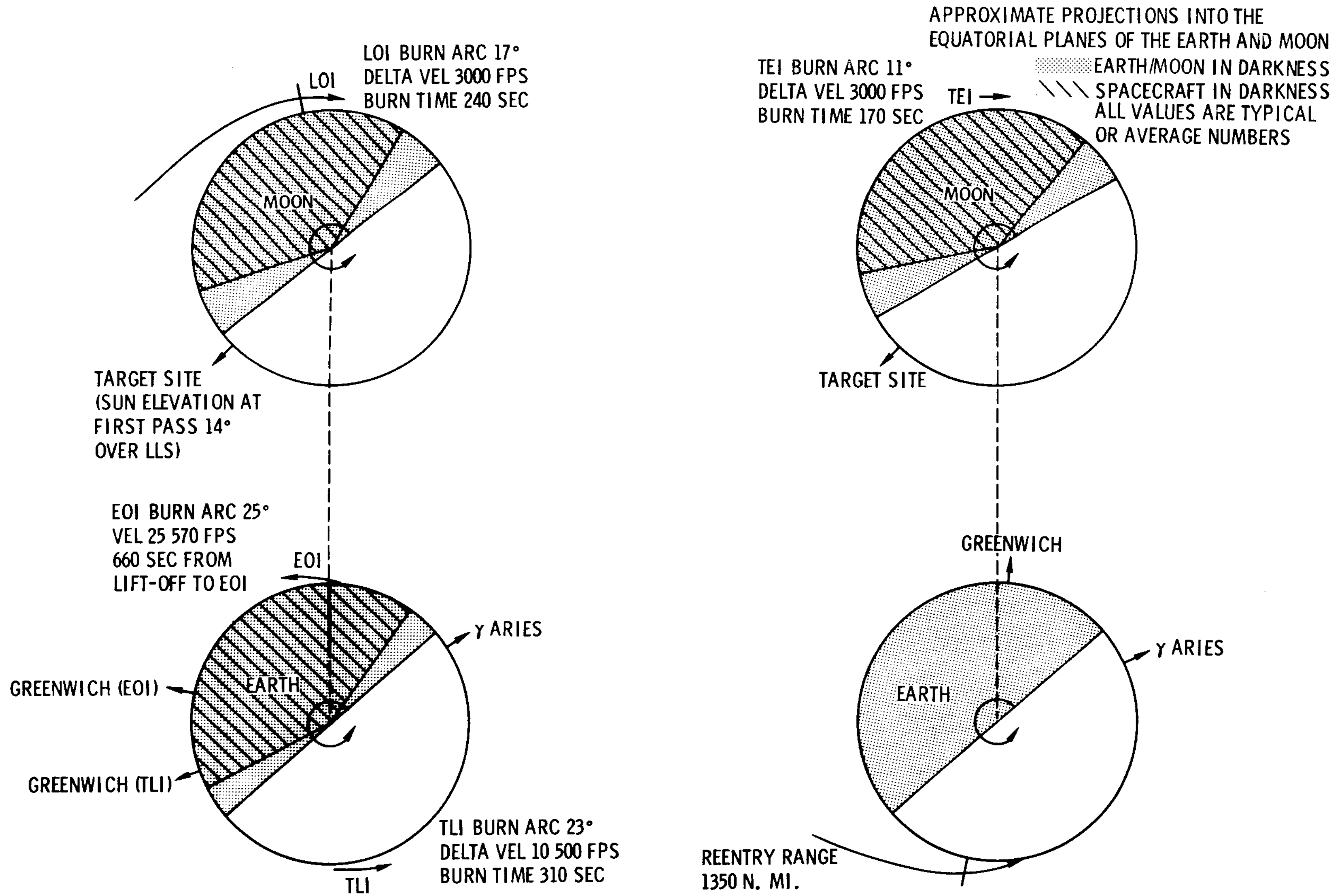
(b) 108 degree launch azimuth.

Figure 6.- Concluded.



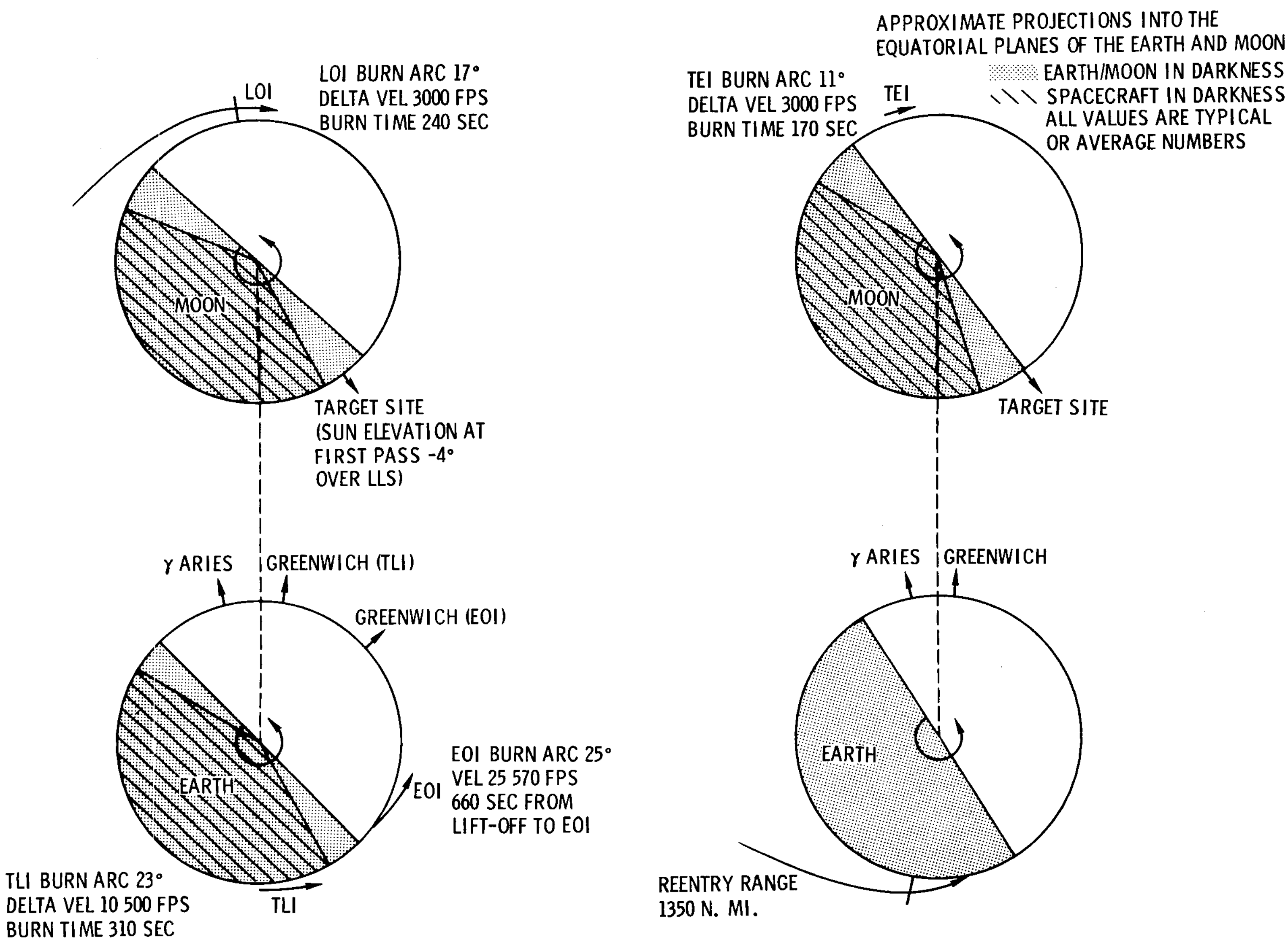
(a) 72 degree launch azimuth.

Figure 7.- Lighting geometry for December 27, 1968.



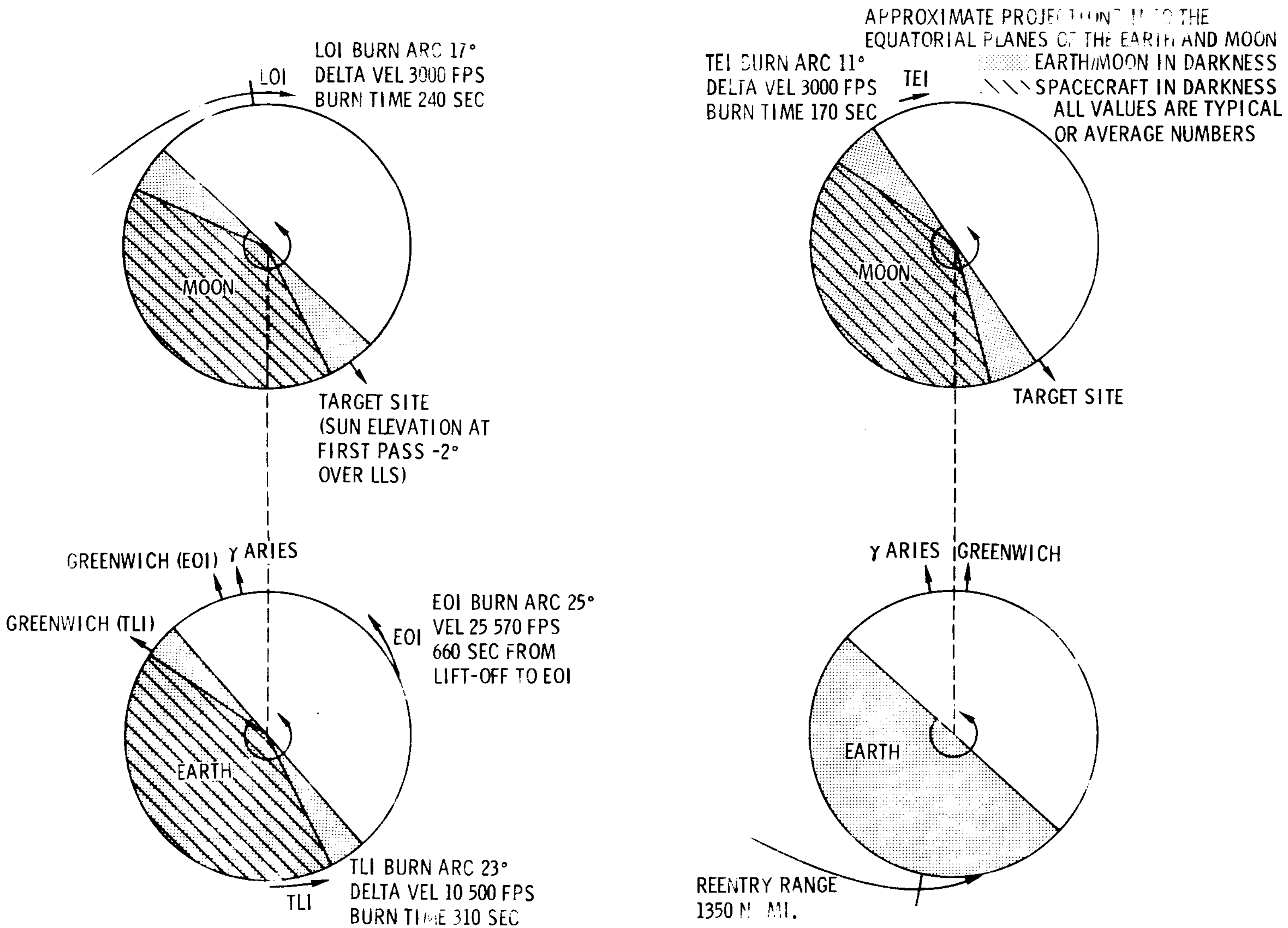
(b) 108 degree launch azimuth.

Figure 7.- Concluded.



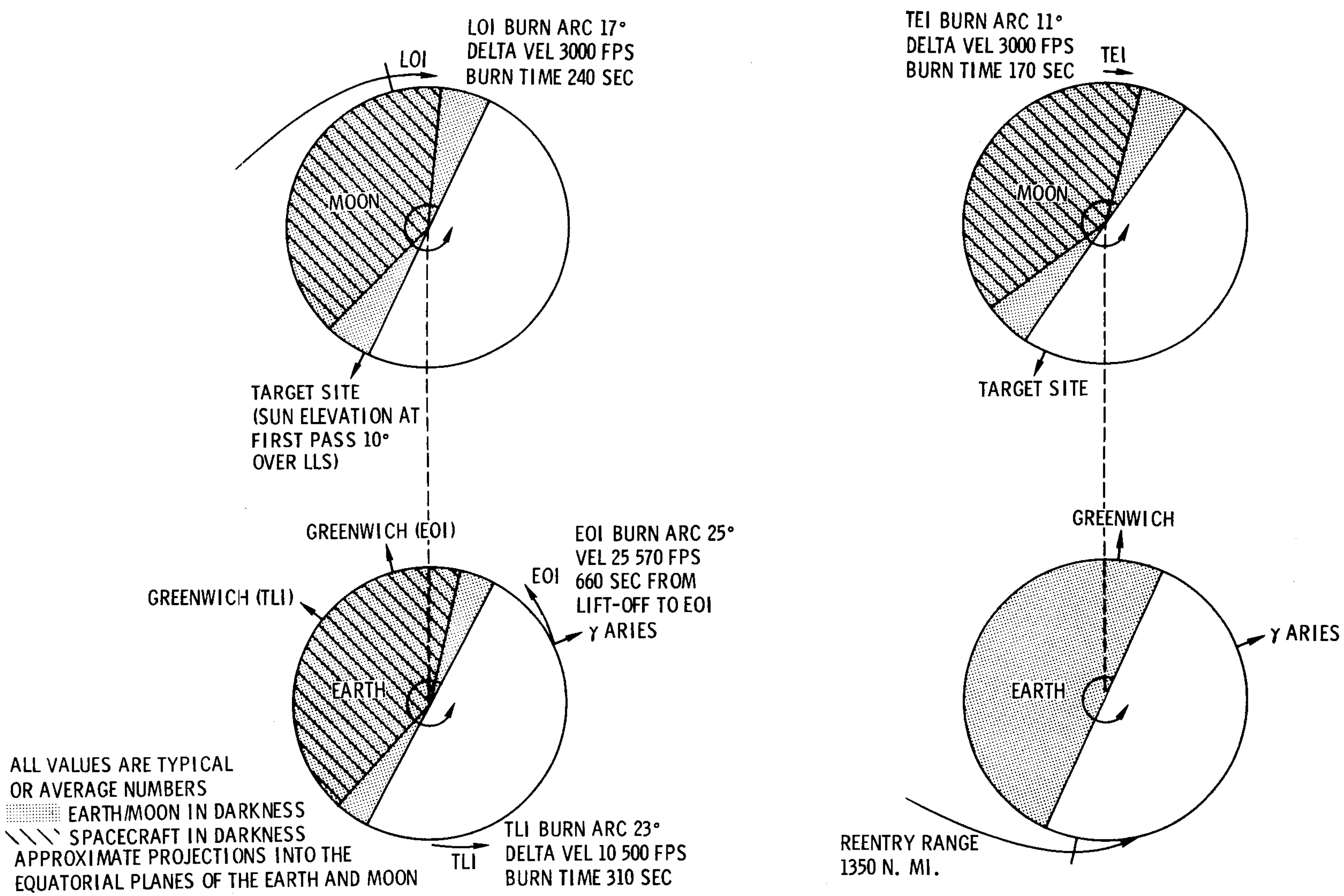
(a) 72 degree launch azimuth.

Figure 8.- Lighting geometry for January 18, 1969.



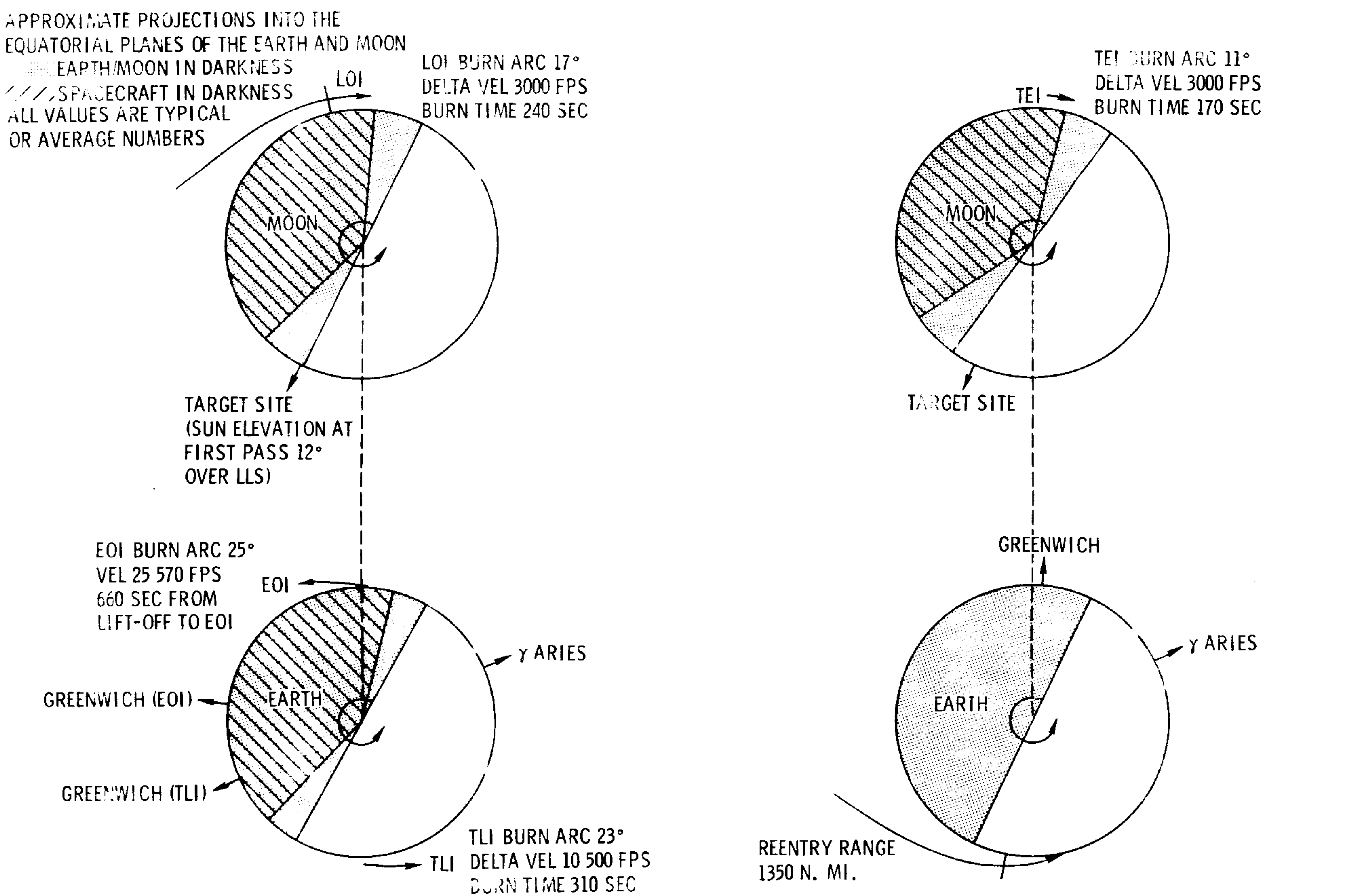
108 degree launch azimuth.

Figure [illegible] - Concluded.



(a) 72 degree launch azimuth.

Figure 9.- Lighting geometry for January 24, 1969



(h) 108 degree launch azimuth.

Figure 9. - Concluded.

REFERENCES

1. LMAB: Apollo Mission C' Spacecraft Operational Trajectory Alternate Alternate 1, Lunar Orbital Mission, Volume I - Mission Profile for a Mission Launched December 21, 1968. MSC IN 68-FM-252, October 25, 1968.

2. LMAB: Apollo Mission C' Spacecraft Operational Trajectory Alternate 1, Lunar Orbital Mission, Volume II - Trajectory Parameters for a Mission Launched December 21, 1968. MSC IN 68-FM-253, October 8, 1968.